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# Study of “multi-core” air showers with EAS array "Carpet-2"

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An experiment has been performed using Baksan "Carpet-2" Air Shower array to study “multi-core” air showers. "Carpet-2" consists of a large area central detector (196 $m^2$), 6 outer detectors and a big underground 1 GeV muon detector of 175 $m^2$ area. The distance between muon detector and the center of array is equal to 48 m. Events with jets of high density ($\rho$>10 relativistic particle per $m^2$) were observed in the muon detector. These events could be interpreted as “multi-core” air showers with high transverse momentum. But, we have found another unexpected interpretation.

## 1. Experiment

The “Carpet-2” array [1] is very convenient instrument for studying Extensive Air Shower (EAS) central structure due to its very large continuous central detector consisting of 400 individual liquid scintillator detectors of 0.5 $m^2$ each. Energy deposit measuring in each detector makes it possible to see the EAS core structure. Our big Muon Detector (MD) [2] (5x35 $m^2$) situated about 48 m apart of the array center consists of 175 plastic scintillator detectors 1 $m^2$ each under of 2.5 m of ground absorber (500 $g/cm^2$) in an underground tunnel on its ceiling. Every detector is provided with a logarithmic RC converter of energy deposit to pulse duration with ½ of relativistic particle threshold. This makes it possible to see the structure of muonic component with 1 GeV threshold energy. There are 3 different triggers which can be used in the experiment: M1 is usual EAS trigger produced by 5-fold coincidence of the central detector and 4 outer detectors (9 $m^2$ each) situated at a radius of 30 m around the center; M2 is special EAS trigger produced by high enough energy deposit (>50 rel. particles.) in the central detector and M3 is MD trigger produced by coincidences of 3 from 5 MD modules (every 35=5x7 detectors of MD are grouped in 5 modules). Multi-core events have been studied with “Carpet” array in the past years [3]. The aim of this experiment was searching for events with high transverse momentum when EAS core is located in the central detector and high energy jets of muons are seen in the MD.

## 2. Experimental data

Strange events were found when EAS core is undoubtedly located in the central Carpet and one or more “bundles of muons” with local density > 10 particles per $m^2$ are seen in MD. An example of such event is shown in Figure1. This picture represents density maps as measured by Carpet (left, shown in LOG scale) and by MD (right, linear scale in relativistic particles). As one can see, the core is located inside the Carpet (x0=0.35m and y0=3.2m from the center as shown by a circle). Detector in the center shows a particle density $\rho_c=8*1.12^{52}/0.5=5800\ m^{-2}$. If one believes that a jet of (26+17)/2=21.5 particles per $m^2$ in MD is caused by muons then some strange features could be obtained. First: the bundle size is very narrow (~1 m) with normal rather low density around it and second: the distance from the EAS core is large enough and equal to 49 m. Taking into account that energy of parent mesons (pions and kaons) could be higher by a factor of 10 and taking a height of muon production of ~10000 m one could make an estimation for transverse momentum as: $p_t$ >43*10*49/10000>2 GeV/c. Note that EAS size of the event is only little bit higher of our threshold ($10^5$ ). This example is one of the simplest. We observed also events with many such "jets" and with energy much higher. We found rather trivial explanation of such kind of events. It is given below.

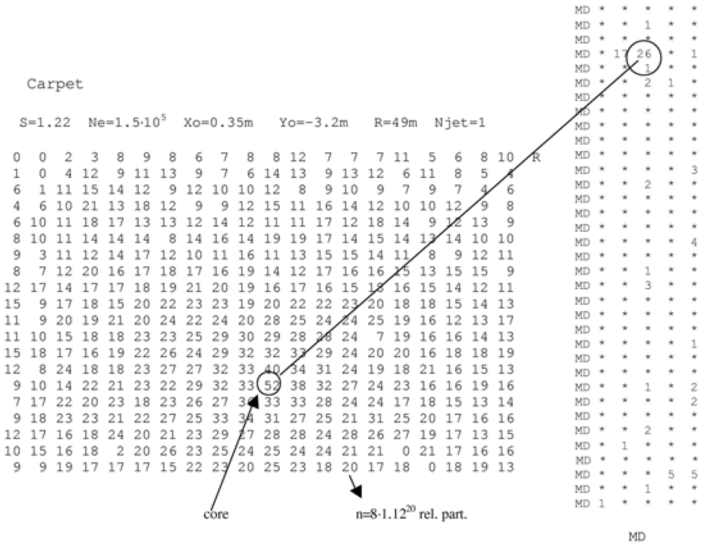


**Figure 1.** An example of a "multi-core" event. Left panel is the Carpet density map (LOG scale), right panel is the MD density map (linear scale).Age parameter (s), EAS size (Ne), core location (x0, y0) and other found parameters are shown.

## 3. Data analysis

The explanation of such events can be easily found if we suppose that they are caused by hadrons of a few GeV energy. Sure, a number of hadrons is lower than that for muons. But, in contrast to muons they interact in 500 g/cm$^2$ of soil absorber with 100% probability. The thickness of the absorber is equal to ~20 radiation lengths and it is enough to absorb electromagnetic component but it is not enough for hadronic cascade (only ~5 hadron interaction lengths). Hadronic cascade developing in the absorber can produce high-energy deposit ε in the scintillator because it is situated just near the hadronic cascade maximum. The higher hadron energy $E_h$ – the higher is energy deposit ε. Estimation gave ratio of $E_h$ /ε ~100. This means that hadron with energy of 10 GeV gives deposit of 100 MeV, i.e. equivalent of ~9 rel. particles in 5 cm plastic. To check this hypothesis we measure first of all the barometric coefficient for such events. It was found to be equal to (0.9±0.1) % / mm of Hg. This confirms our hypothesis. Another confirmation was obtained from Monte Carlo simulation using CORSIKA code (HDPM model). Energy spectra of muons and hadrons traversing our MD for M2 trigger with additional event cuts (Ne>$10^5$ and axis inside the Carpet) are shown in Figure2. As one can see a probability to see hadrons with E>1 GeV in MD is close to 1 for primary iron and ~0.5 for primary proton. Therefore, the appearance of a few-GeV hadron in MD can be observed almost in each event after such selection. The energy of these hadrons is enough for imitate a "jet" or "bundle of muons" in our detectors. Experimental fraction of events with "jets" of ε>10 r. p. in MD was found to be 17%. This figure is very close to the calculated probability to find hadron with E>11 GeV shown in Figure 2 for proton primaries. It is interesting that ceiling location of the detectors makes the energy deposit spots very sharp. In

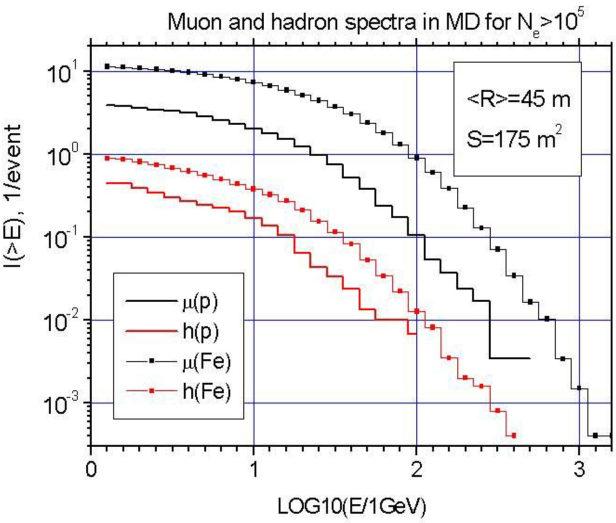


**Figure 2.** Calculated energy spectra of muons (black) and hadrons (red) in MD for selected events for primary p and Fe.

a case of floor detectors location cascade particles would have enough air spacing (2.5 m) for lateral spread resulting in bigger spots with lower particle density.Returning to the event shown in Figure1 one can see that a total number of hadrons in it is probably equal to 6 (7?) because all hitted detectors with energy deposit ε higher than 2 particles should be assigned to hadrons, while a number of muons ($\varepsilon \leq 2$) is equal to 15. We can also estimate the energy of all 6 hadrons as: 47 (29+18); 5.5; 5.5; 4.4; 3.3; 3.3 GeV.

## 4. Conclusion

Making this experiment we found a new interesting phenomenon. A number of hadrons in muon detectors is not equal to 0. Figure 2 displays that hadron to muon ratio is equal to ~ 10% at low energy at a distance of 40-50 m and should not be neglected. This means that hadrons can produce some unexpected effects in muon detectors especially in cases when absorber is not thick (<1000 g/cm$^2$) and the detector is located close to the core. This also means that hadrons can imitate muons in muon detectors in events with high multiplicity making the tail of multiplicity spectrum flatter.Another consequence of this work is very interesting from a methodic point of view. A muon detector with thin absorber can also be used as a hadron detector! Moreover, in a case similar to our one when the muon detector has a large continuous area constituent from many individual detectors able to measure energy deposit, then it can be used as a hadronic calorimeter. We plan to continue this work and try to measure EAS hadron size distributions for various triggers and even try to measure hadron energy spectrum. This effect providing additional information will also be used in future data analysis.

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## References

[1] E.N.Alekseev, V.V.Alekseenko et al. Izvestia AN SSSR, ser. Fiz., v.38, (1974), 1097
[2] N.A.Alekseenko, V.V.Alekseenko et al., Proc. of 23d ICRC, Calgary, v.2, (1993), 477
[3] A.E.Chudakov, D.D.Dzhappuev, A.S.Lidvansky et.al. Proc. 18th ICRC, Bangolore, v.6, (1983), 29